Ray tracing calculations for the 3 pole wigglers

Manuel Sanchez del Rio

OUTLOOK

Introduction to Source modeling in SHADOW

- Geometric
- BM and Wiggler

Wiggler

- Results for first 3-pole wiggler design
- Results for new design
- To do

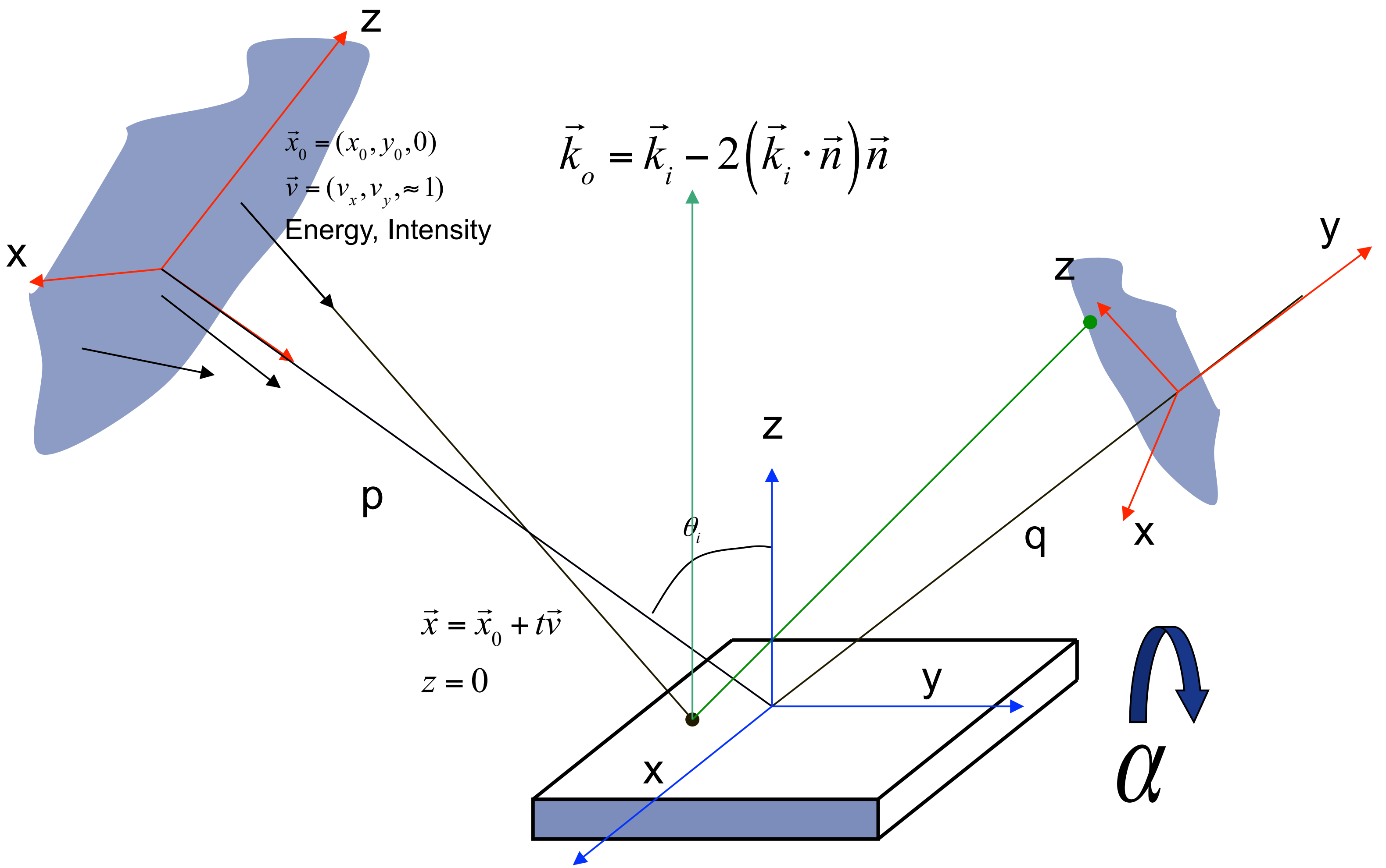
Ray = array of 18 float (called columns – rows are number of rays):
($\mathbf{x}$, $\mathbf{v}$, $\mathbf{E}_\sigma$, lost_flag, $|\mathbf{k}|=2\pi/\lambda$, index, OP, ϕ_σ, ϕ_π, $\mathbf{E}_\pi$)
3 3 3 1 1 1 1 1 1 3 = 18 => there is redundancy

We cal easily define other variables ("compound columns"):

11: E [eV]
19: λ [A]
20: $r = (x^2 + y^2 + z^2)^{1/2}$
21: angle from Y axis
22: $|E| = | E_\sigma + E_\pi|$
23: $I = |E|^2$
24: $I_\sigma = |E_\sigma|^2$
25: $I_\pi = |E_\pi|^2$
26: k
27-29: (k_x,k_y,k_z)
30-32 Stokes $= \{ I_\sigma+I_\pi, I_\sigma-I_\pi, 2 |E_\sigma| |E_\pi| \cos(\phi_\sigma-\phi_\pi), 2 |E_\sigma| |E_\pi| \sin(\phi_\sigma-\phi_\pi)) \}$

A single ray is always monochromatic
A beam is a collection of rays

Trace (the beamline)



GEOMETRIC SOURCES

Fill with given distributions (flat, Gaussian, etc)
(**x**, **v**, $\mathbf{E}_\sigma$, lost_flag, |**k**|=$2\pi/\lambda$, index, OP, ϕ_σ, ϕ_π, $\mathbf{E}_\pi$)

E.g.,
point source x={0,0,0},
collimated source v={0,0,1}
Note that
$|v| = 1$, $I = |\mathbf{E}_\sigma + \mathbf{E}_\pi|^2 = 1$ at the source

$\phi_\pi = \phi_\sigma$ + phase difference
ϕ_σ is usually random (incoherent rays one to another)

In geometric sources, **x**, **v** and **E** are uncorrelated:
The sampling order is not important.
Once created the source, a variable can be resampled

$$(A_s)^2 + (A_p)^2 = 1$$

. SHADOW prompts the user for the phase difference in degrees between ϕ_s and ϕ_p. The Degree of polarization determines the relative amplitude of the s and p vectors according to the relation :

$$Degree\ of\ polarization = \cos(\theta)/(\cos(\theta) + \sin(\theta))$$

where θ is the angle of polarization from the As axis.

Some examples of polarization states:
- Linearly polarized:
  - Phase difference $= 0$
  - Degree of polarization = whatever the above expression is when the desired value of θ is plugged in.
    - for $\theta = 45$ deg, $DOP = 0.50$
    - for $\theta = 30$ deg, $DOP = 0.63$
- Circularly polarized:
  - Phase diff $= +90$ (for Right), -90 (for Left)
  - Degree of Polarization $= 0.5$

Monte Carlo (source model)

INVERSION

REJECTION

THE INSTITUTE FOR ADVANCED STUDY
SCHOOL OF MATHEMATICS
PRINCETON, NEW JERSEY

May 21, 1947

Mr. Stan Ulam
Post Office Box 1663
Santa Fe
New Mexico

Dear Stan,

Thanks for your letter of the 19th. I need not tell you that Klari and I are looking forward to the trip and visit at Los Alamos this Summer. I have already received the necessary papers from Carson Mark. I filled out and returned mine yesterday; Klari's will follow today.

I am very glad that preparations for the random numbers work are to begin soon. In this connection, I would like to mention this: Assume that you have several random number distributions, each equidistributed in $0, 1$: (x^i), (y^i), (z^i), ... Assume that you want one with the distribution function (density) $f(\xi)\,d\xi$: (ξ^i). One way to form it is to form the cumulative distribution function: $g(\xi) = \int^{\xi} f(\xi)\,d\xi$ to invert it $h(x) = \xi \rightleftarrows x = g(\xi)$, and to form $\xi^i = h(x^i)$ with this $h(x)$, or some approximant polynomial. This is, as I see, the method that you have in mind.

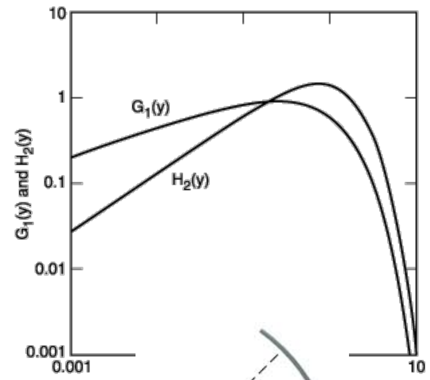
An alternative, which works if ξ and all values of $f(\xi)$ lie in 0, 1, is this: Scan pairs x^i, y^i and use or reject x^i, y^i according to whether $y^i \leq f(x^i)$ or not. In the first case, put $\xi^j = x^i$ in the second case form no ξ^j at that step.

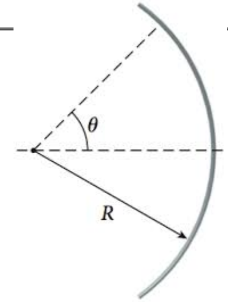
The second method may occasionally be better than the first one. In some cases combinations of both may be best; e.g., form random pairs $\xi = \sin x$, $\eta = \cos x$ with x equidistributed between 0° and 300°. The obvious way consists of using the sin - cos - tables (with interpolation). This is clearly closely related to the first method. This is an alternative procedure:
Put

$$\xi = \frac{2t}{1+t^2}, \quad \eta = \frac{1-t^2}{1+t^2}, \quad t = tg\, y,$$

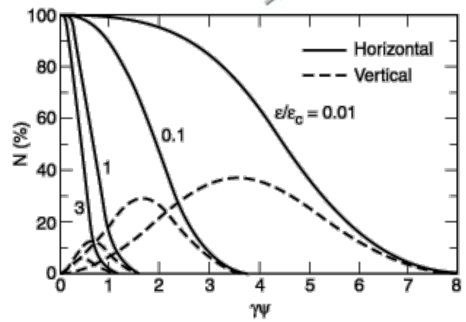
with y (which is $\frac{x}{2}$) equidistributed between 0° and 180°. Restrict y to 0° to 45°. Then the ξ, η will have to be replaced randomly by η, ξ and again by $\pm\xi, \pm\eta$. This can be done by using random digits 0, . . . , 7. It is also feasible with

1) Sample Energies from BM spectrum (pre-calculated or exact)
2) Sample position (uniformly distributed over the trajectory arc)
3) Sample direction
   - -Tangent to trajectory in H
   - -Correlated to photon energy: Sample angle following, get DOP from |Es|/|Ep| ratio





Add emittance effects:
1) Ask σ,σ' and waist position (for H and V)
2) Compute e^- beam size distribution at the ray starting position
3) Sample a random value using this bivariate Gaussian distribution (for H and V)
4) Add it to the ray position **x** and direction **v**

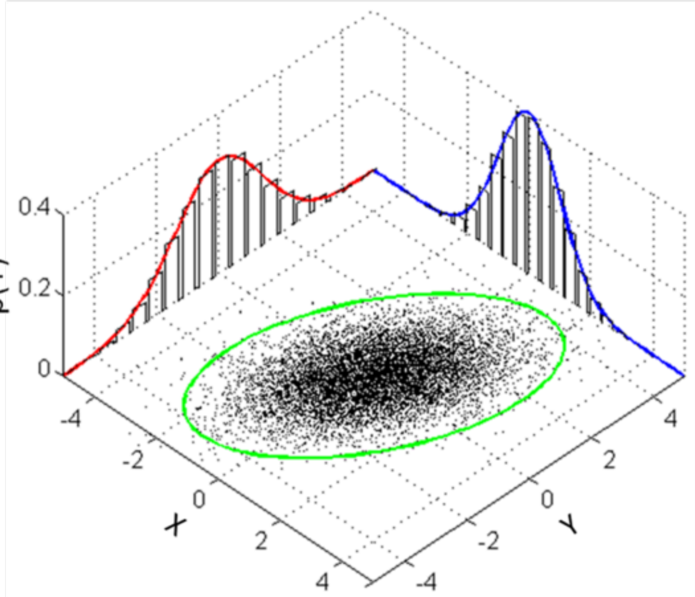


Good:
   Exact model for emission, good geometry characteristics (depth, curvature),

Limitations:
   i) No edge radiation
   ii) the e- beam size at a given position *s* is obtained from the waist position supposing we are in free space (no magnetic field) => small effect in general => to be checked and upgraded!
   iii) No energy spread

COMPUTE E⁻ BEAM SIZES

At s (any point of the trajectory):



Bivariate Normal Distribution

$$\Sigma = \begin{pmatrix} \langle x^2 \rangle & \langle xx' \rangle \\ \langle xx' \rangle & \langle x'^2 \rangle \end{pmatrix} = \begin{pmatrix} \beta_x \varepsilon_x & -\alpha_x \varepsilon_x \\ -\alpha_x \varepsilon_x & \gamma_x \varepsilon_x \end{pmatrix} + \eta^2 \sigma_\delta{}^2 I_{2x2}$$

Evolution in empty space

$$\langle x^2 \rangle_y = \langle x^2 \rangle + 2\langle xx' \rangle y + \langle x'^2 \rangle y^2$$
$$\langle xx' \rangle_y = \langle xx' \rangle + \langle x'^2 \rangle y$$
$$\langle x'^2 \rangle_y = \langle x'^2 \rangle$$

With ε the emittance (constant), and Twiss parameters:

$$\sigma_x = \sqrt{\langle x^2 \rangle} = \sqrt{\beta_x \varepsilon_x}; \quad \sigma_{x'} = \sqrt{\langle x'^2 \rangle} = \sqrt{\gamma_x \varepsilon_x}; \quad \sigma_x \sigma_{x'} = \varepsilon_x \sqrt{1+\alpha_x^2} \quad \alpha = -\frac{1}{2}\frac{d\beta}{ds}; \quad \gamma = \frac{1+\alpha^2}{\beta}$$

At waist (zero correlation, ρ=α=0, β is minimum):

$$\sigma_x = \sqrt{\langle x^2 \rangle} = \sqrt{\beta_x \varepsilon_x}; \quad \sigma_{x'} = \sqrt{\langle x'^2 \rangle}\Big|_w = \sqrt{\frac{\varepsilon_x}{\beta_x}}; \quad \boxed{\sigma_x \sigma_{x'} = \varepsilon_x}$$

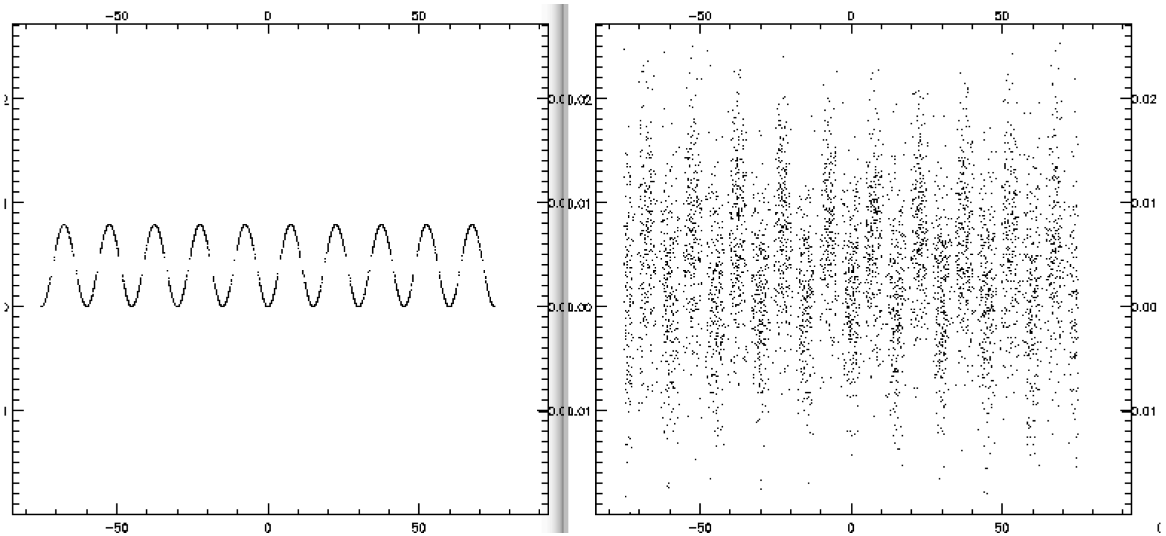
WIGGLER MODEL IN SHADOW: SINGLE ELECTRON

Calculate

- Spectrum (full emission)
- Trajectory
- Velocities (directions or angles)
- Curvature (1/R)

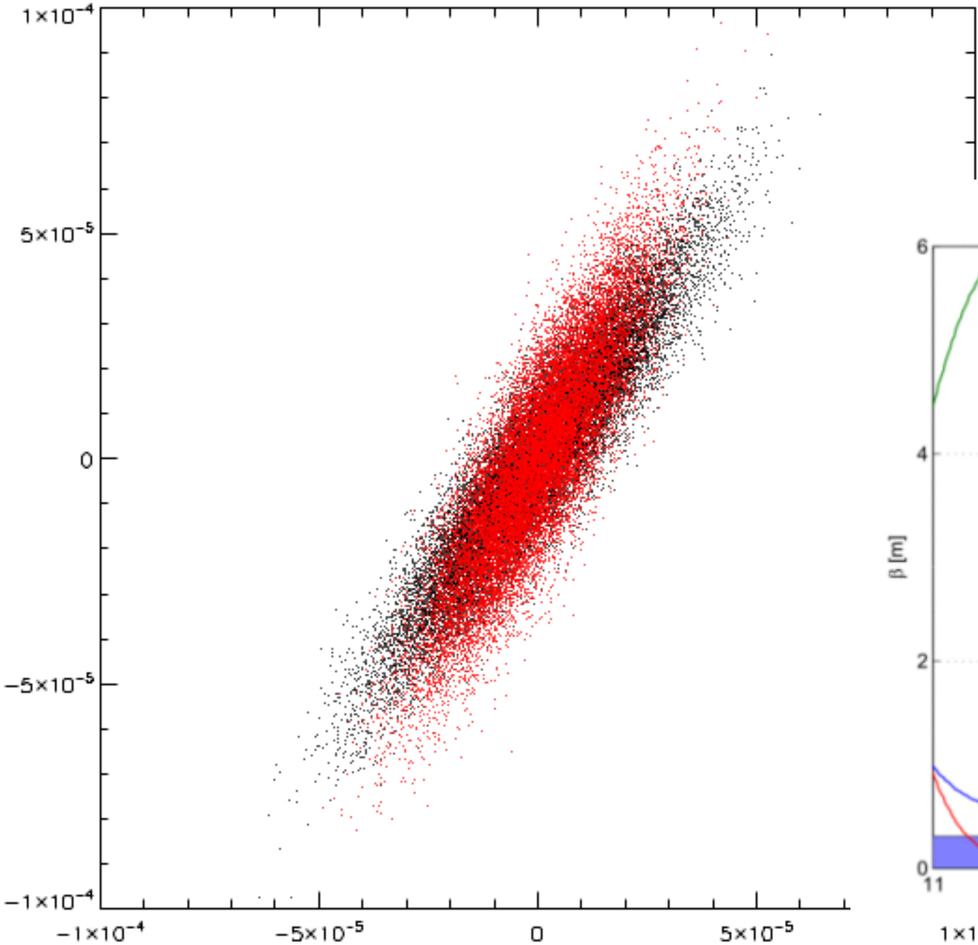
Sample:

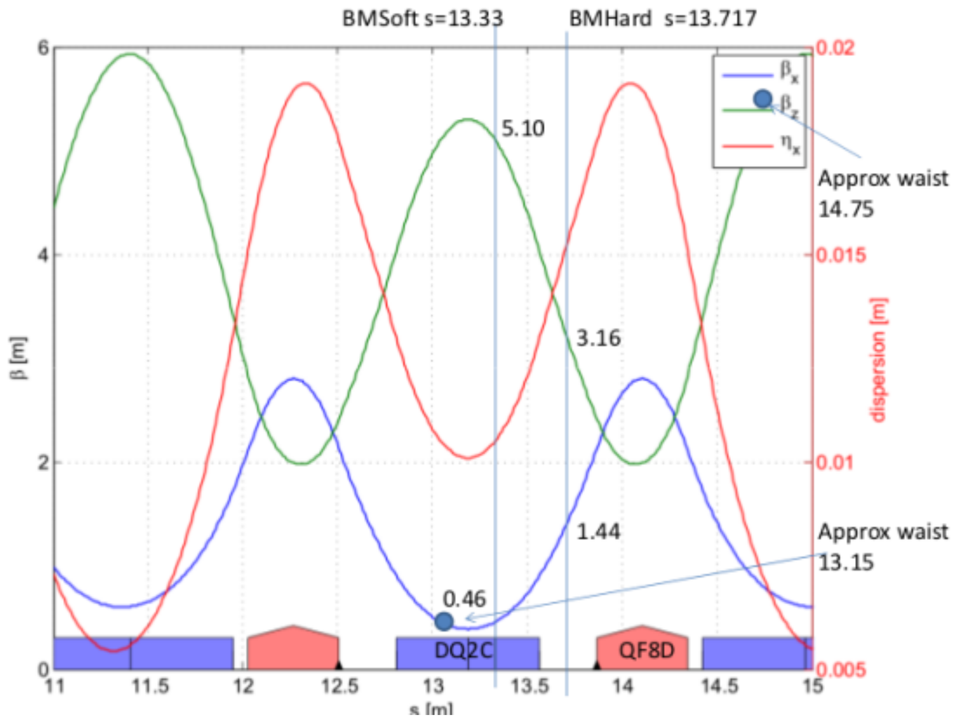
- photon energy
- position in the trajectory (not uniform, sampling from curvature)
- angle: H tangent to trajectory
  - V: Sampled from BM distributions for the local magnetic radius



WIGGLER MODEL IN SHADOW: ELECTRON PARAMETERS

3PW at the ESRF new lattice

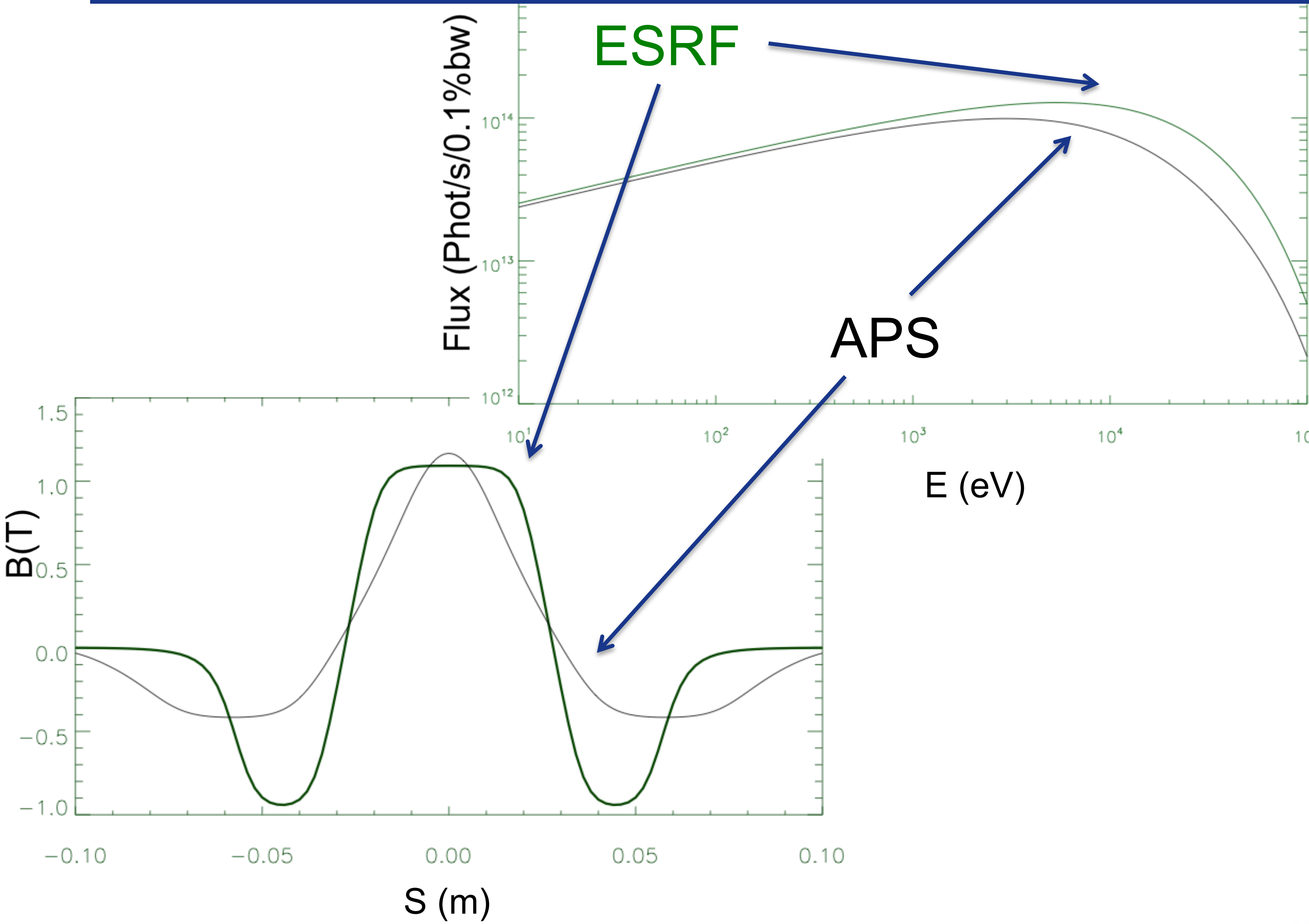


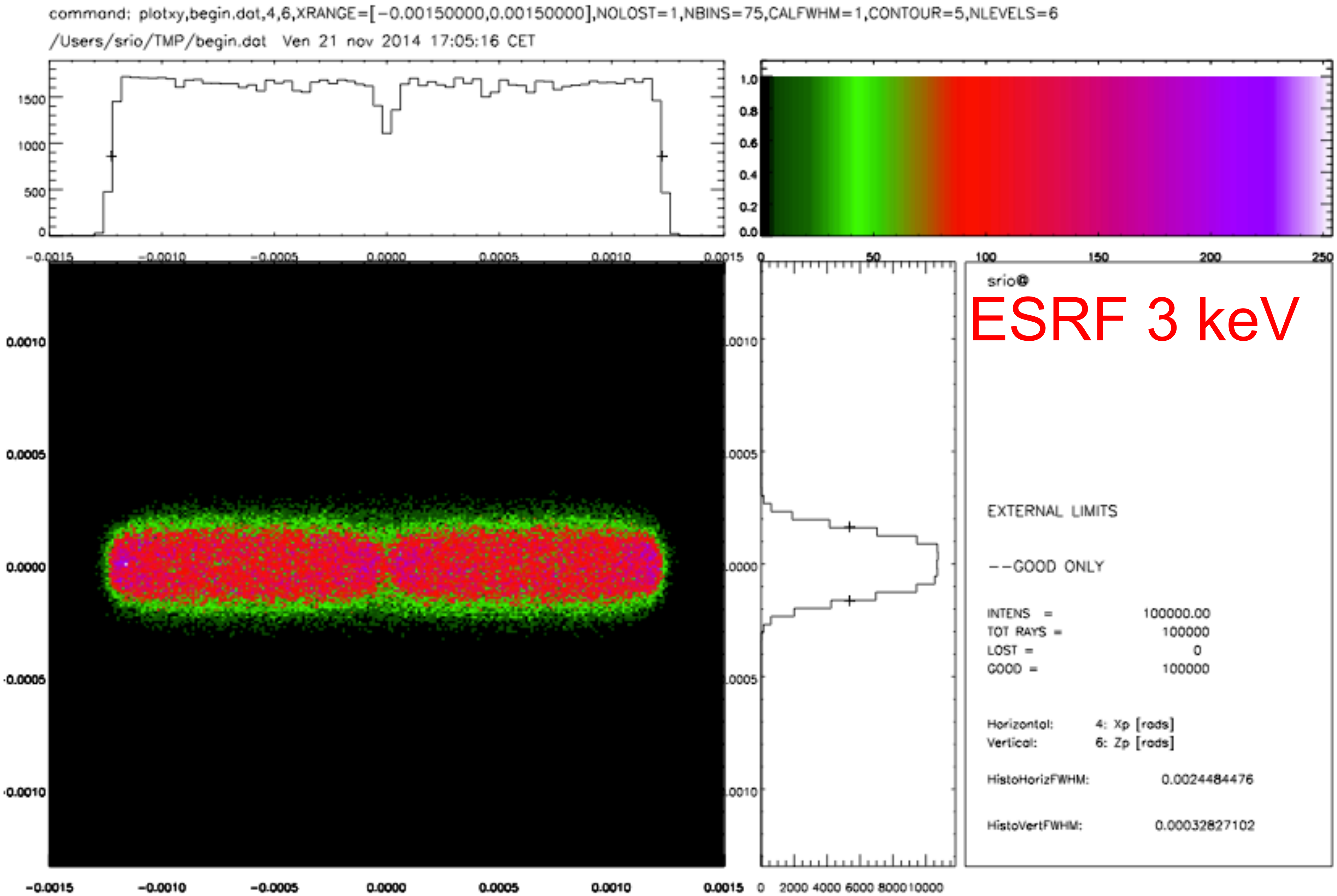


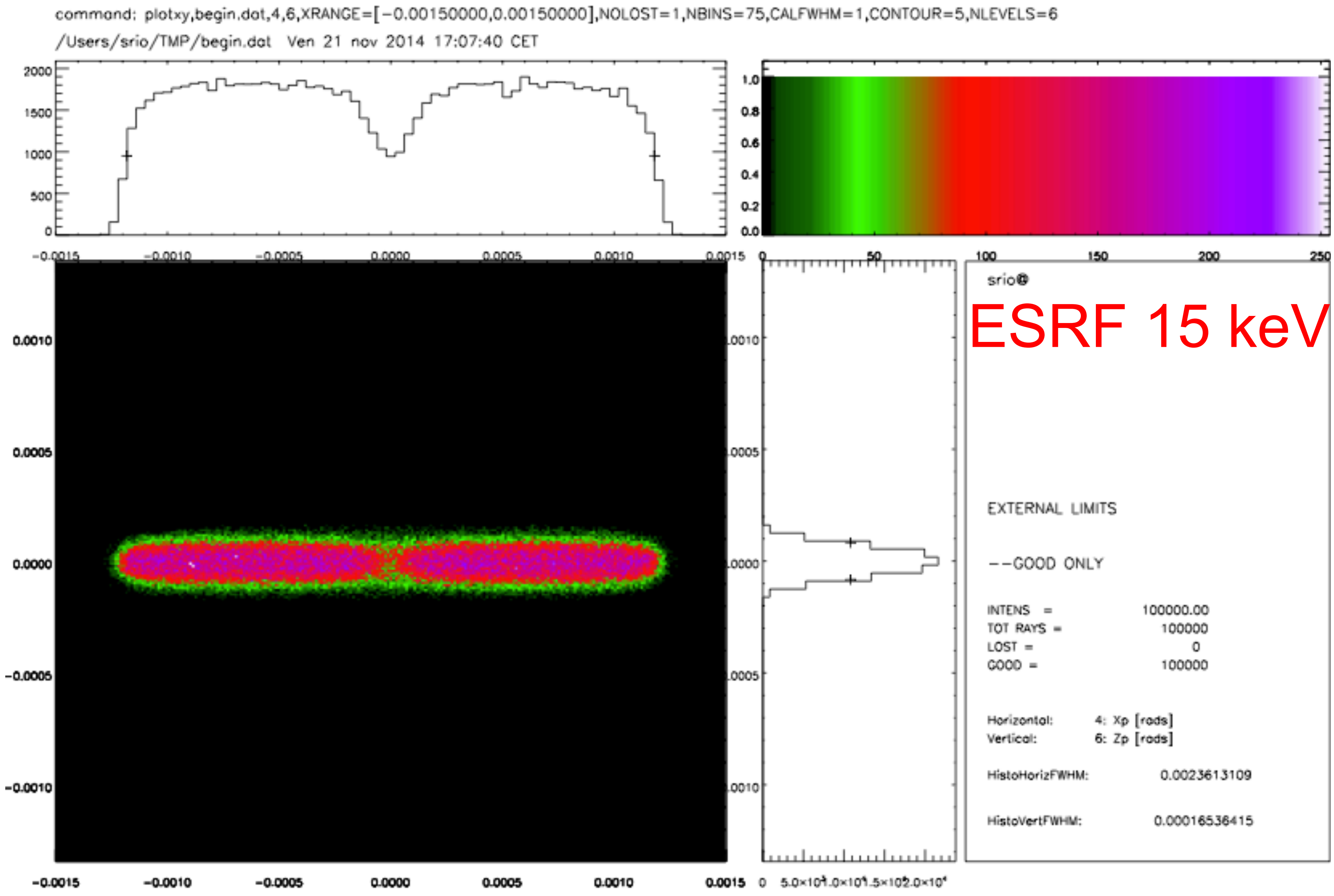
3: Monte Carlo sampling of the electron phase space $x'[rad]$ vs. $x[m]$ at gler edges: $y = -0.1$ (red) and $y = 0.1$ (black).

Implementation in SHADOW: http://forge.epn-campus.eu/documents/784

3PW COMPARISON




command: plotxy,begin.dat,4,6,XRANGE=[-0.00150000,0.00150000],NOLOST=1,NBINS=75,CALFWHM=1,CONTOUR=5,NLEVELS=6
/Users/srio/TMP/begin.dat Ven 21 nov 2014 17:05:16 CET
srio@
ESRF 3 keV
EXTERNAL LIMITS
--GOOD ONLY
INTENS = 100000.00
TOT RAYS = 100000
LOST = 0
GOOD = 100000
Horizontal: 4: Xp [rads]
Vertical: 6: Zp [rads]
HistoHorizFWHM: 0.0024484476
HistoVertFWHM: 0.00032827102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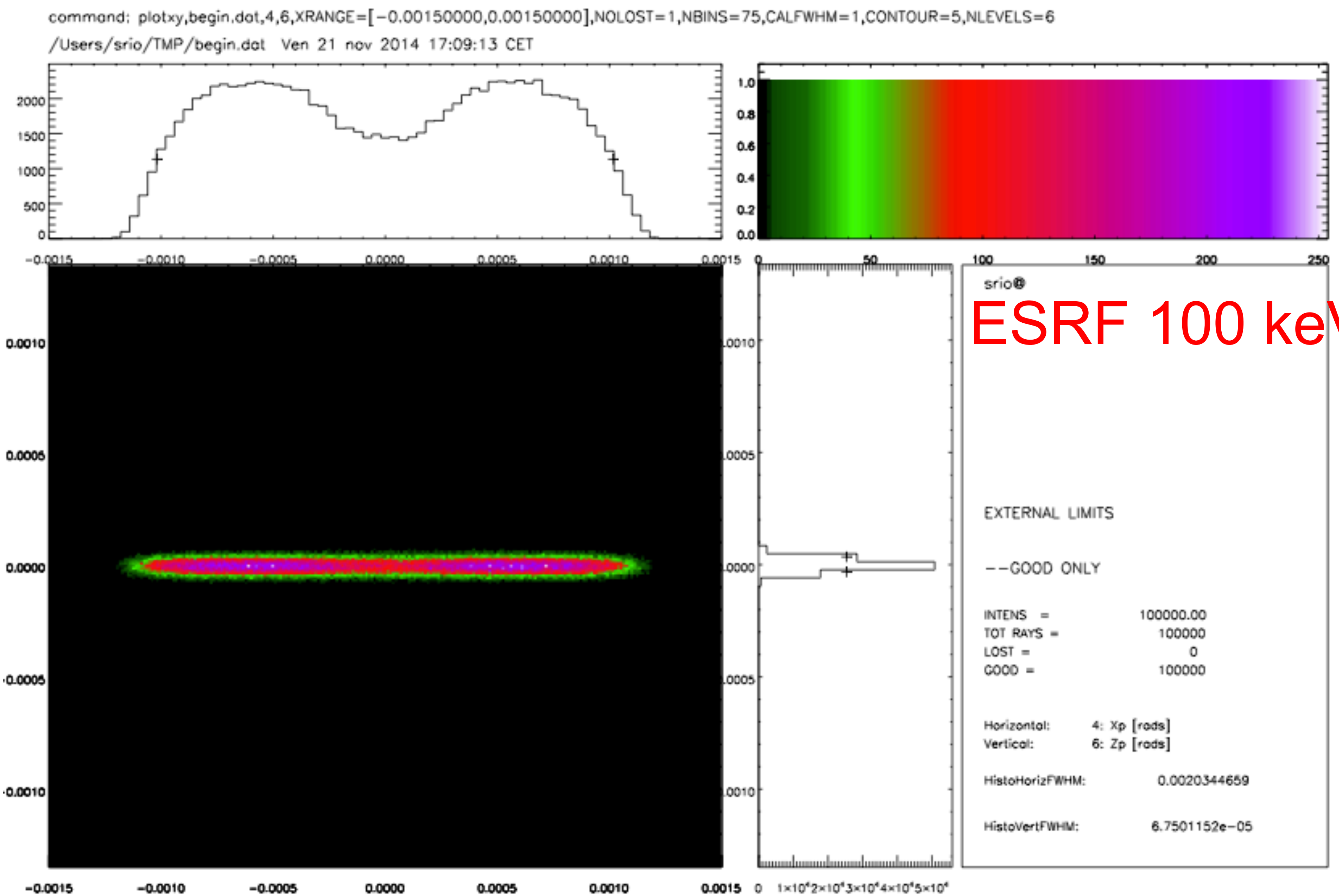
/Users/srio/TMP/begin.dat Ven 21 nov 2014 17:07:40 CET
srio@
ESRF 15 keV
EXTERNAL LIMITS
--GOOD ONLY
INTENS = 100000.00
TOT RAYS = 100000
LOST = 0
GOOD = 100000
Horizontal: 4: Xp [rads]
Vertical: 6: Zp [rads]
HistoHorizFWHM: 0.0023613109
HistoVertFWHM: 0.00016536415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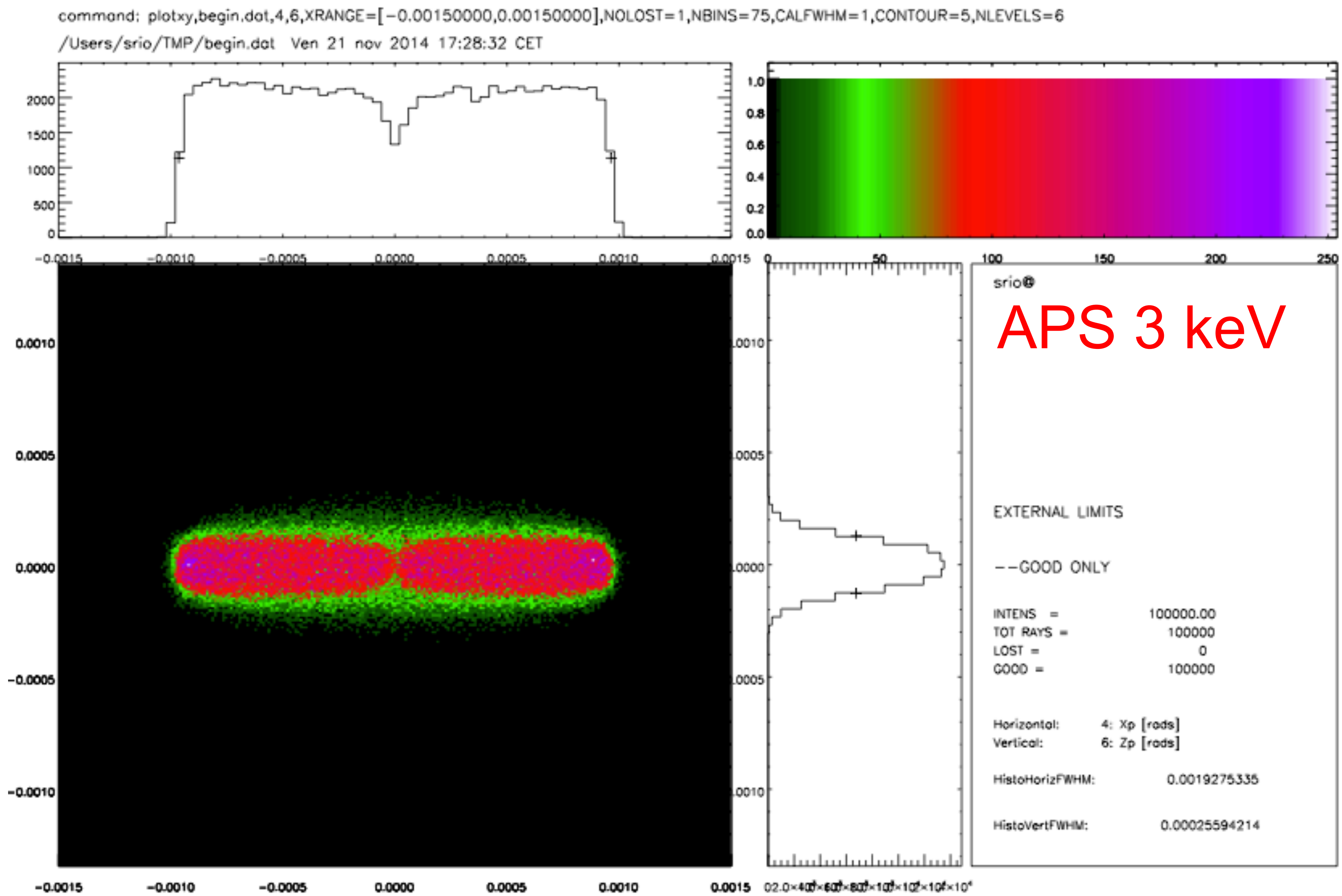
/Users/srio/TMP/begin.dat Ven 21 nov 2014 17:09:13 CET
srio@
ESRF 100 ke
EXTERNAL LIMITS
--GOOD ONLY
INTENS = 100000.00
TOT RAYS = 100000
LOST = 0
GOOD = 100000
Horizontal: 4: Xp [rads]
Vertical: 6: Zp [rads]
HistoHorizFWHM: 0.0020344659
HistoVertFWHM: 6.7501152e-05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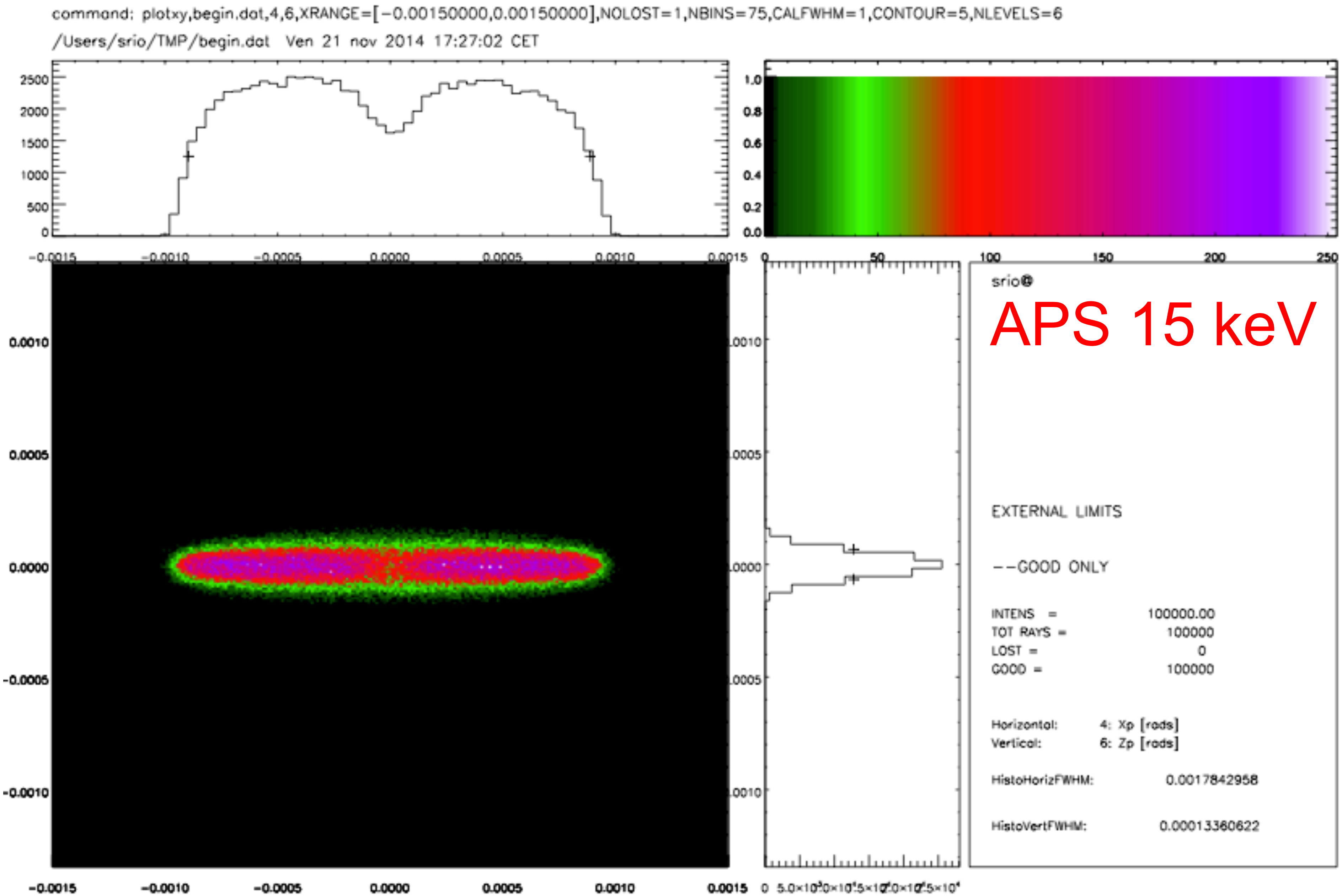
/Users/srio/TMP/begin.dat Ven 21 nov 2014 17:28:32 CET
srio@
APS 3 keV
EXTERNAL LIMITS
--GOOD ONLY
INTENS = 100000.00
TOT RAYS = 100000
LOST = 0
GOOD = 100000
Horizontal: 4: Xp [rads]
Vertical: 6: Zp [rads]
HistoHorizFWHM: 0.0019275335
HistoVertFWHM: 0.00025594214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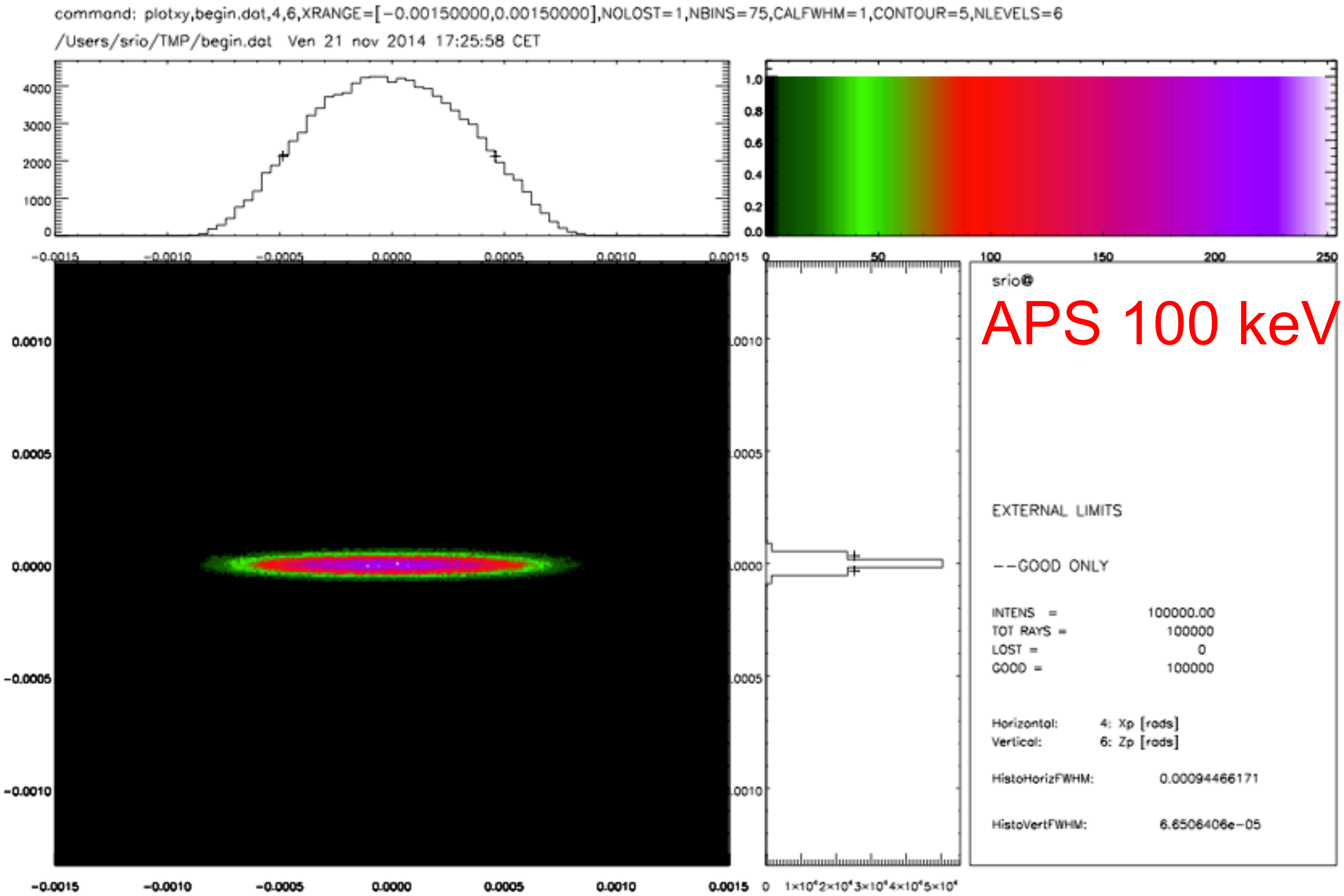
srio@
APS 15 keV
EXTERNAL LIMITS
--GOOD ONLY
INTENS = 100000.00
TOT RAYS = 100000
LOST = 0
GOOD = 100000
Horizontal: 4: Xp [rads]
Vertical: 6: Zp [rads]
HistoHorizFWHM: 0.0017842958
HistoVertFWHM: 0.00013360622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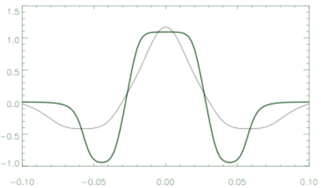
srio@
APS 100 keV
EXTERNAL LIMITS
--GOOD ONLY
INTENS = 100000.00
TOT RAYS = 100000
LOST = 0
GOOD = 100000
Horizontal: 4: Xp [rads]
Vertical: 6: Zp [rads]
HistoHorizFWHM: 0.00094466171
HistoVertFWHM: 6.6506406e-05

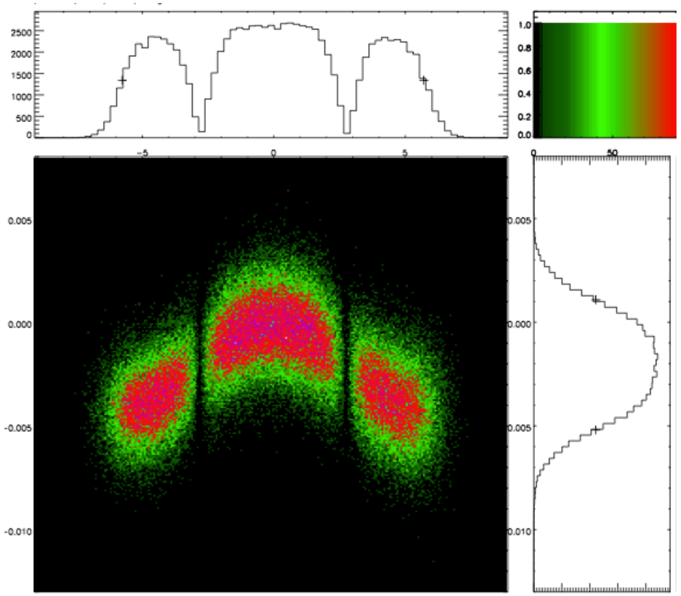
Emission – Top view

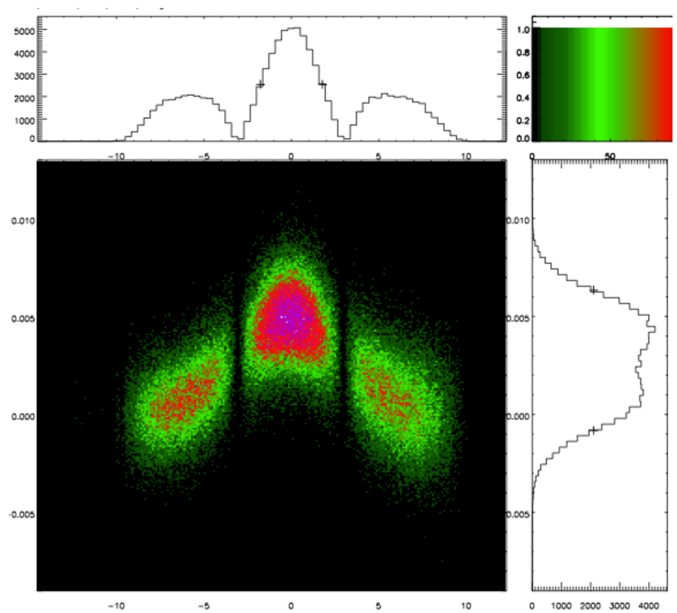


ESRF

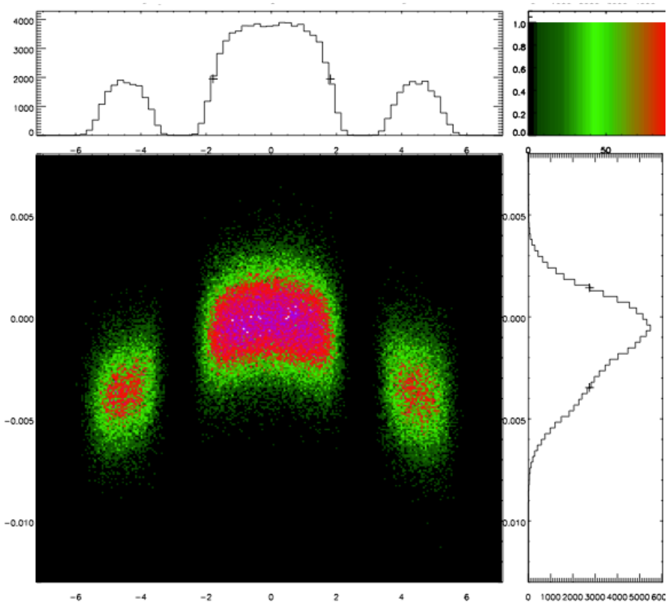
APS

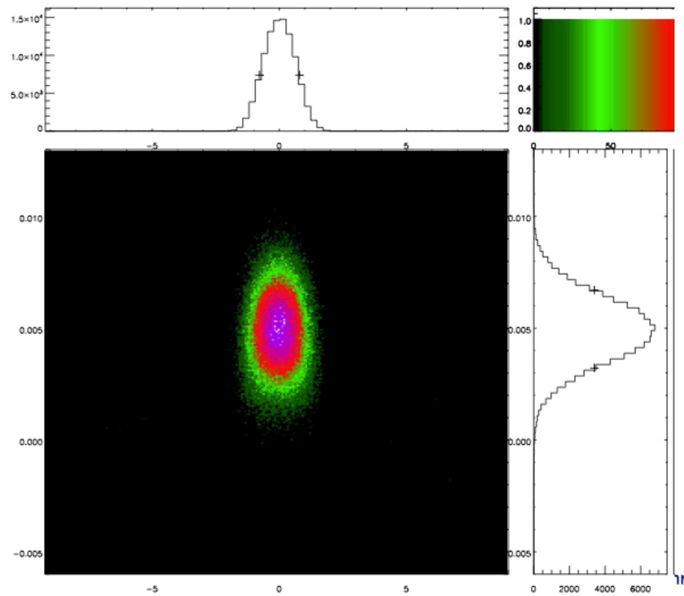
3 keV

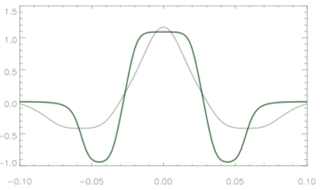




100 keV



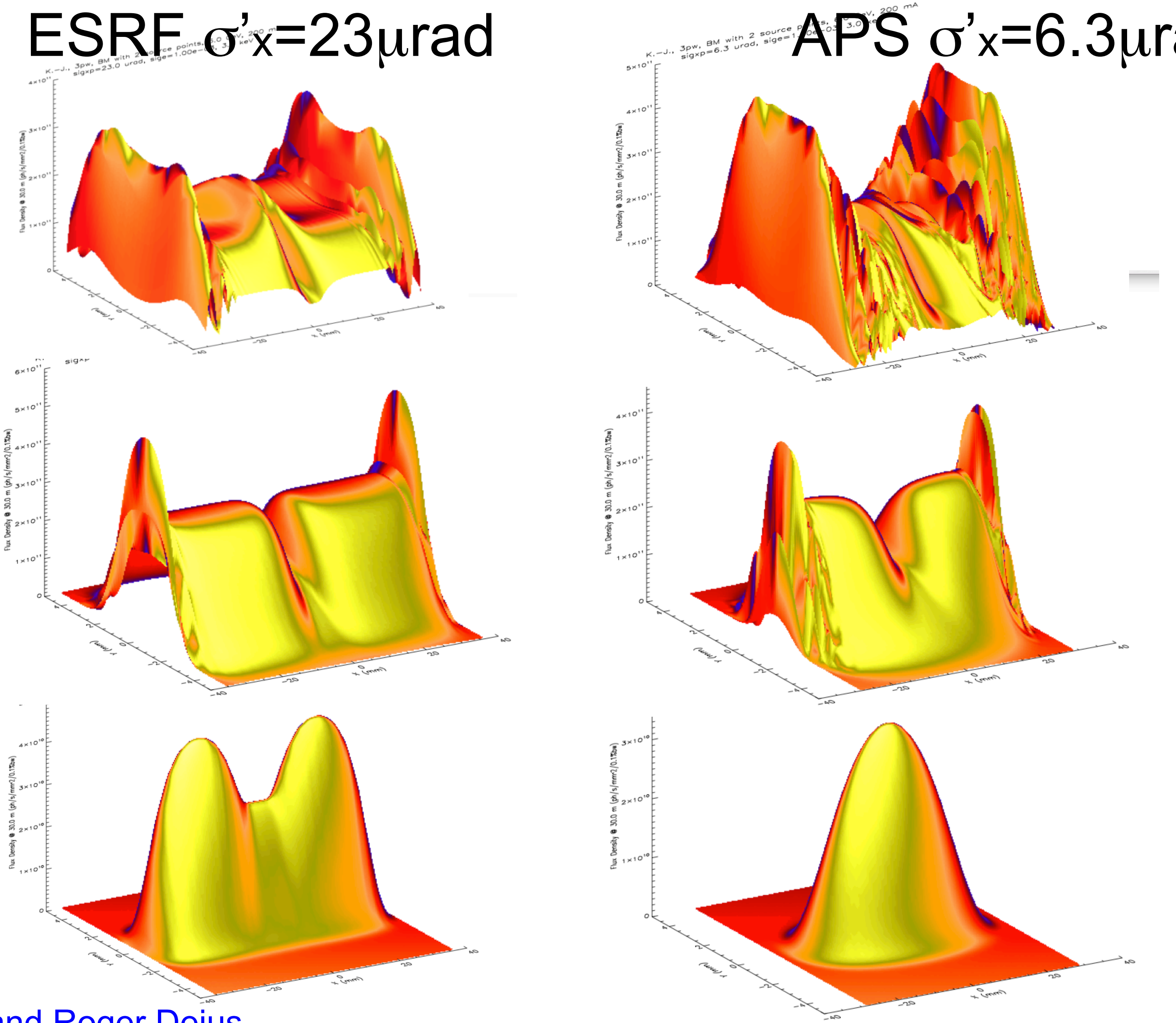




Beam profile @ 30m

ESRF σ'_x=23μrad

APS σ'_x=6.3μrad



3 keV

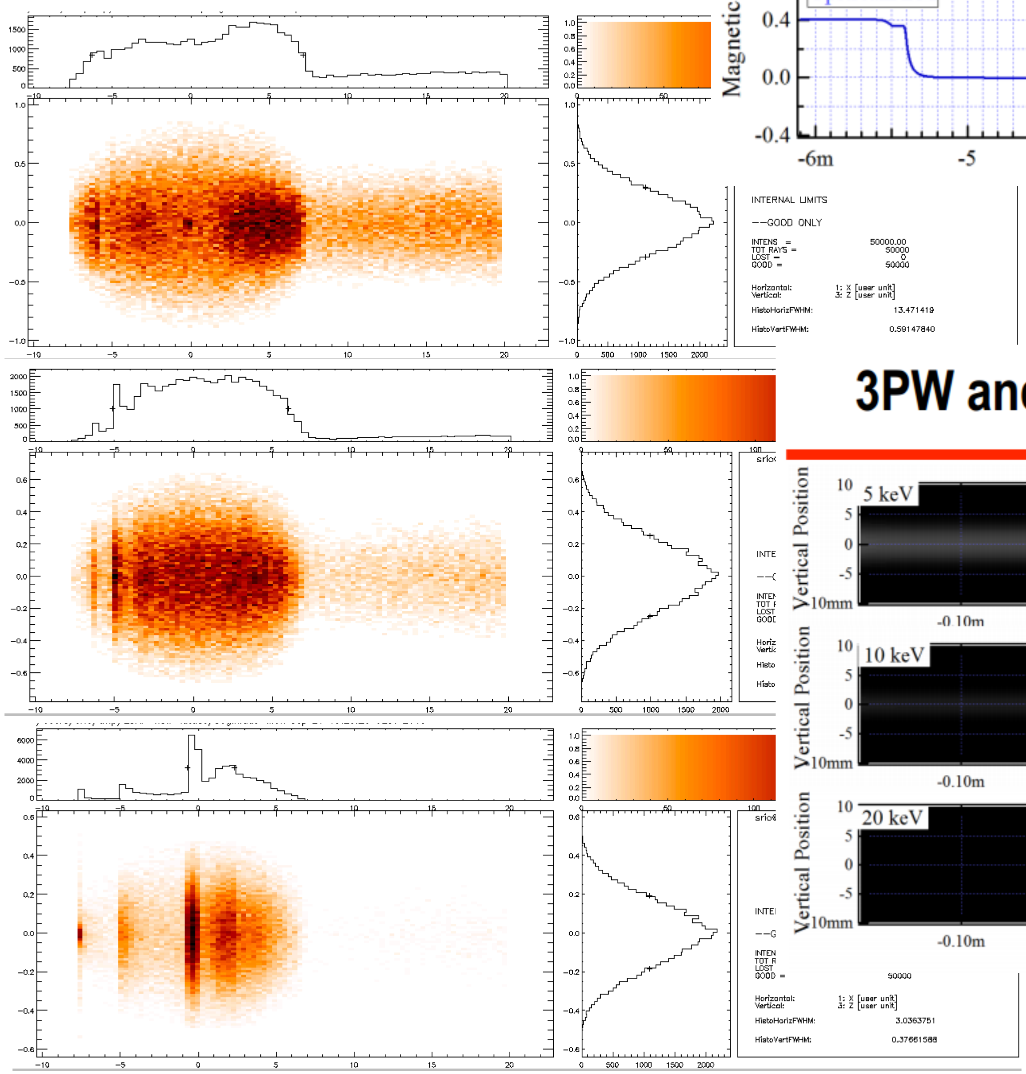
15 keV

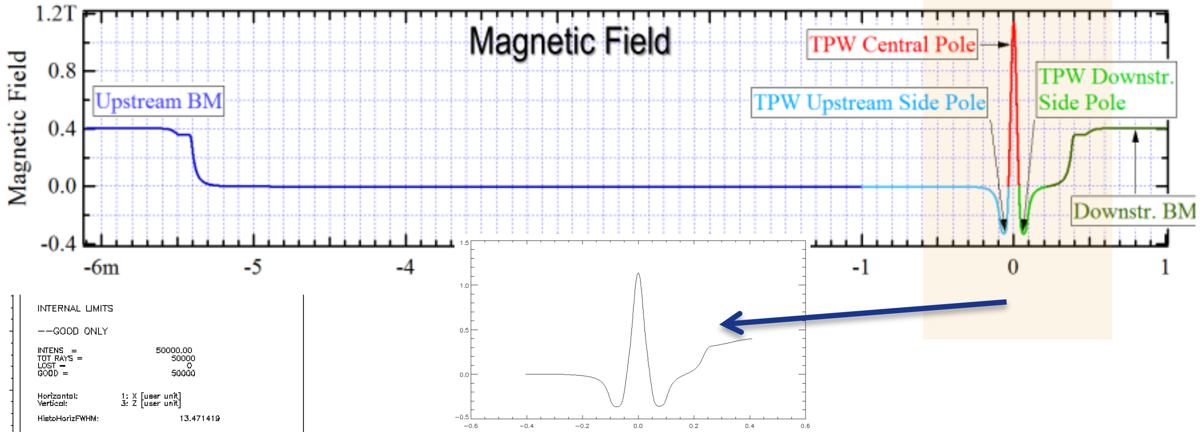
100 keV

Kwang-Je Kim and Roger Dejus

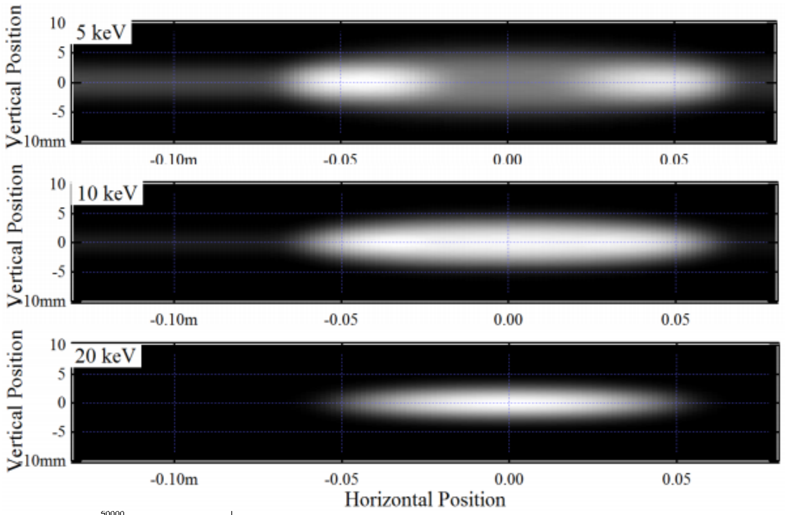
Sharpness of Interference Pattern of APSU 3-Pole Wiggler - MD-TN-2014-003

NSLS-II 3PW SHADOW-NO EMITTANCE





3PW and BM Intensity Distributions (Hard X-rays



- Intensity distributions a different photon energi 30 m from 3PW show from soft poles in 3PW from adjacent BMs
- Effect of such non-idea intensity distribution or microfocusing is being by a working group, an updates will be provide

•Calculation with DEJUS?

3PW – OVERLAPPING WITH BM

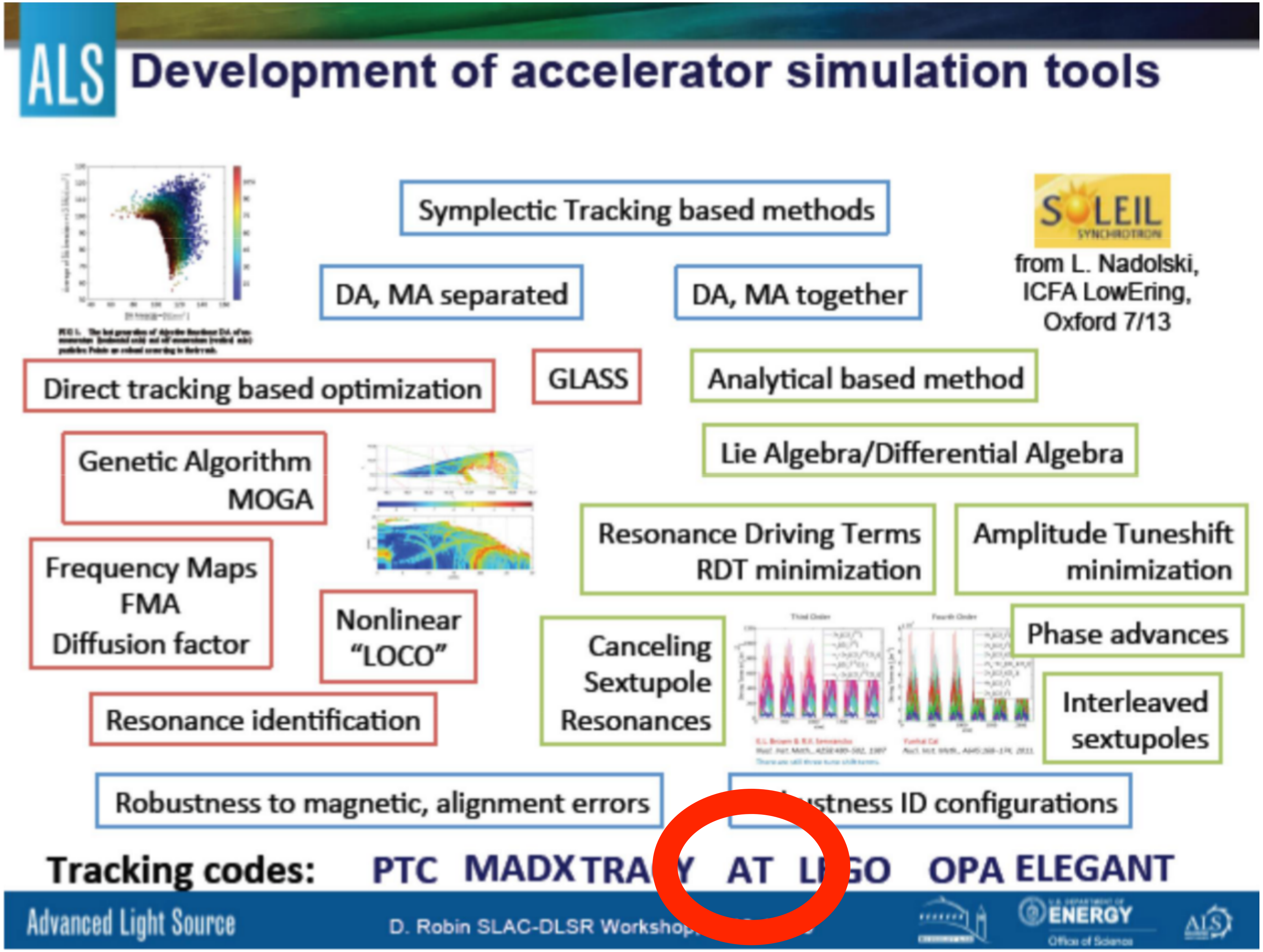
- There is an overlap with the BM radiation of the downstream BM
- Adding BM fields in SHADOW. Problems:
    - The axes for SHADOW are in the direction of the entrance electron, so the optical axis is not correctly placed
    - Emittance values not correctly set because is not empty space but there is magnetic fields (BMs, QP) [not dramatic…]
    - Still the problem of interpolation errors…
- Shortcuts:
    - Shift (to the e- starting position) and rotate (center of the wiggler at zero angle) the source

AUTOMATIC AND PRECISE INSERTION OF STORAGE RING PARAMETERS

- PRESENT WAY:
  - Look for values published (reports, web, …) and copy them
  - Talk to accelerator people
  - Values change… Tabulations are incomplete, and do not include all "interesting points"

- NEW WAY
  - Ring parameters from accelerator codes (internal formats…)
  - Run codes to obtain a tabulation of the Twiss parameters, moments, etc. at the desired $[s_1,s_2]$ interval
  - Use this as input to sample rays in SHADOW, etc.

CALCULATE/IMPORT ELECTRON BEAM CHARACTERISTICS



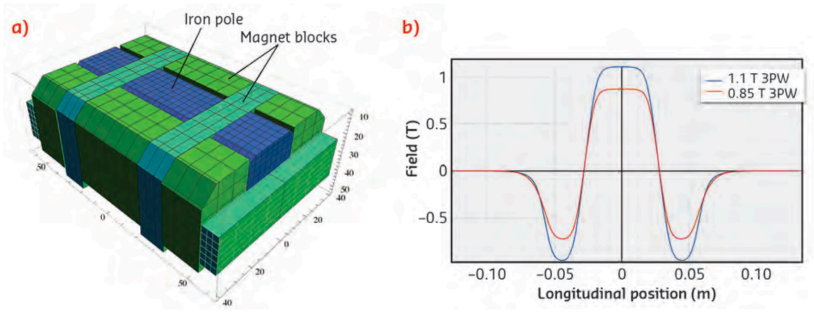
EXAMPLE AT TO SHADOW

I want in a file with:

s B <xx> <xx'> <x'x'> <yy> <yy'> <y'y'>

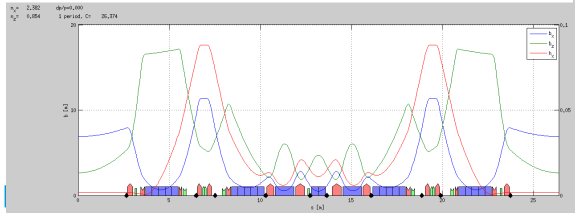
Magnetic field:

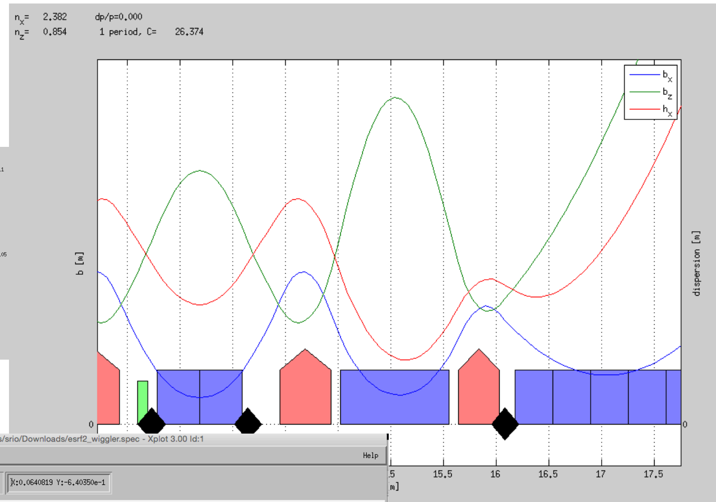
wiggler sources



AT provided these *plots* :

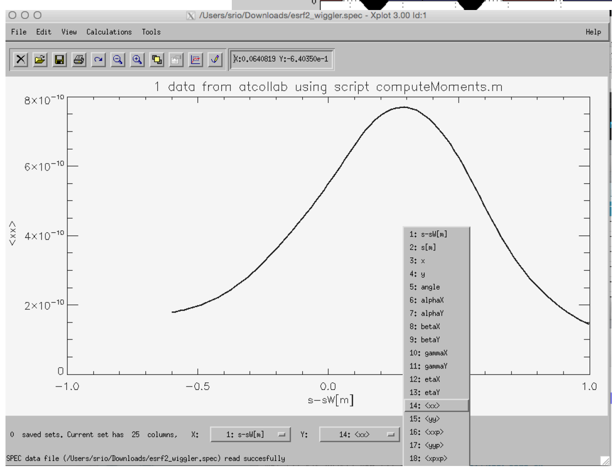
```
load("S28CINJ.mat")
atplot(ARCA)
```





Boaz helped to make a

to drop Twiss pars and moments



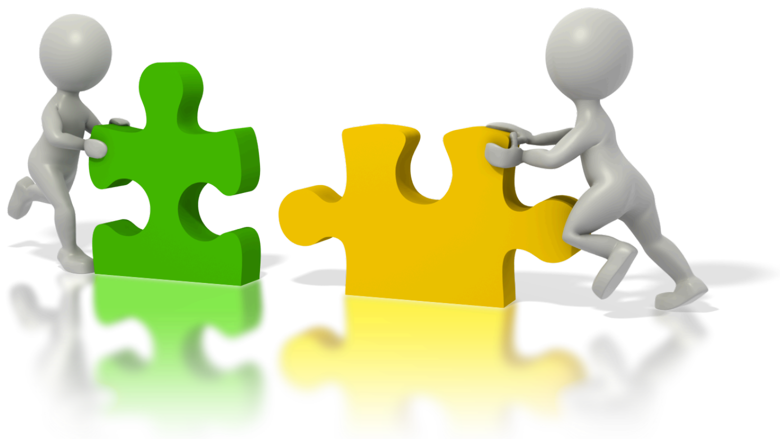
TODO:

Match them!!

Modify shadow3

Automatize?

THE END



Thanks!